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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

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No. 1132

POSSIBILITIES OF REDUCING THE LENGTH OF AXIAL
SUPERCHARGERS FOR AIRCRAFT MOTORS

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SUPERCHARGERS FOR AIRCRAFT MOTORS*

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SUMMARY

With the increase of engine outputs, that is, with the demand for greater quantities of compressed air, axial blowers gain increasing importance as aircraft-engine superchargers. With centrifugal blowers, great altitudes and great engine outputs result in large over-all diameters, which make difficult the connection of blower to motor gearing, and in any case make an aerodynamically good fitting of the motor into the nacelle very doubtful. The great volume capacity of the axial blower meets the requirements. But the wider introduction of axial superchargers has been delayed because the pressure head obtainable per stage is relatively small. Due to the necessary great number of stages, the physical length of the blower thus becomes too great for an airworthy device. In the following, several types of construction will be described that permit a reduction in this length.

POSSIBILITIES OF REDUCING BLOWER LENGTH

(a) Increasing the Pressure Factor

The development of the rotors with the aim of greater pressure increase per stage leads to a useful reduction of blower length. The possibilities of raising the pressure increase per rotor by means of appropriate blade design and precision manufacture of the blades on special machinery have been successfully exploited. (See references 1, 2, and 3.) An increase of pressure by raising the speed of the rotor has so far been found possible without a drop in efficiency only when the relative velocities are kept below the speed of sound.

*"Möglichkeiten der Baulängenverkürzung bei Axial-Flugmotorenladern." Tech. Berichte, ZWB, TB 4, Jahrg. 1940, pp. 130-133.

(b) Mechanical Design Measures to Decrease Supercharger Length

Figure 1 shows the normal construction of an axial supercharger, developed and built in the Research Institute for Automobiles and Engines, Stuttgart Technical College, to have the following theoretical characteristics:

Air delivered $G = 1.1$ kilograms per second

Pressure coefficient per stage (rotor plus stator) $\psi = 0.8$

Peripheral speed of blade tips, $u_a = 280$ meters per second

Here the adiabatic pressure head with z stages is

$$H_{ad} = \psi \frac{u_a^2}{2g} z \text{ [m]}$$

where g is the acceleration of gravity.

Let us now introduce a comparison factor x for various types of axial supercharger construction, which shall be defined as the ratio of the value l/D , in which l signifies the compass of the over-all axial extent of the rotor and D is the maximum outer diameter to the total-pressure factor of the supercharger; that is

$$x = \frac{l/D}{\Sigma\psi}$$

$\Sigma\psi$ is composed of the ψ -values of the rotors and guide vanes. For each rotor in this supercharger, $\psi = 0.7$ may be taken and for each terminal or intermediate guide-vane set $\psi = 0.1$. With the physical measurements from figure 1, the following is obtained for this supercharger:

$$x = \frac{1.056}{2.4} = 0.44$$

In figure 2 is shown another three-stage supercharger, likewise developed at the institute, for an output of 0.85 kilogram per second. In the arrangement of the bearings, constructional measures were taken to reduce the length. The resulting comparison factor was

$$x = \frac{1.06}{2.4} = 0.442$$

Stimulated by work on a control gear for cooling blowers, further possibilities of decreasing blower length were investigated.

In figure 3 is reproduced the design of a four-stage axial supercharger with two clockwise and two counterclockwise rotors. Behind the first rotor stage, a bevel-gear reversing drive is provided for. The second- and third-stage axes therefore revolve oppositely to the first and fourth stages, which are directly connected to the supercharger shaft proper. By taking advantage of this opposite rotation of rotors 1 and 2 and of 3 and 4, two intermediate guide-vane sets and the exit guide vanes may be omitted. With an uneven number of rotors, an exit guide-vane set is, of course, appropriate. For the design shown in figure 3, only an intermediate guide-vane set between the second and third rotors is necessary. Assuming a pressure coefficient per stage of

$$\psi = 0.7$$

the following comparison factor is obtained:

$$x = \frac{0.833}{2.8} = 0.298$$

Figure 4 shows the design of a four-stage axial supercharger with two reversing gears, whereby intermediate guide vanes are entirely dispensed with. Again when the stage pressure coefficient $\psi = 0.7$, for the construction of figure 4

$$x = \frac{0.7225}{2.8} = 0.258$$

The constructional advantages of the design using two reversing gears are even more clearly visible in a five-stage arrangement (fig. 5). A first stage directly connected to the shaft and followed by the same arrangements as in figure 4 gives a comparison factor

$$x = \frac{0.917}{3.6} = 0.225$$

Figure 6 gives the design essentials of an axial supercharger (reference 1) in which two rotor stages are fastened to the shaft and three are fastened to a drum. The comparison factor in this case is

$$x = \frac{0.804}{3.6} = 0.223$$

The comparison factor would thus be even more favorable here than for the designs of figures 3 to 5. However, it must be remarked in connection with this design that for reasons of material strength it is not possible to design a drum for peripheral speeds of 280 meters per second; or, to express it another way, in order to achieve a given pressure head, a greater number of stages and hence a greater blower length will be necessary.

If we allow $u_a = 150$ meters per second as the outside limit of peripheral speed of the drum, then the greatest pressure head will be $H = 4000$ meters, as compared with 14,000 meters for the five-stage arrangement of figure 5.

Besides this, additional flow losses are inevitable with the drum type of design because of the windage losses. Furthermore, in regard to the gear-tooth loading it must be noted that on the basis of figure 6 the power to be transmitted through the bevel-gear drive amounts to three-fifths of the total power used, whereas the power flowing through one bevel-gear drive in the design shown in figure 3 is only one-half, in figure 4 only one-fourth, and in figure 5 only one-fifth of the total power.

As an important advantage of the counter-rotating design it must also be mentioned that the raising of pressure is always more efficient in a rotor than in a stationary set of guide vanes, or in other words, it involves smaller losses.

The relations for the various types of design are shown in summary in table 1.

As shown by a rough check calculation of the gearings and bevel-gear bearings, the demands on the gear wheels for the transmission of the power required in these designs lie within permissible limits.

Translation by Edward S. Shafer,
National Advisory Committee
for Aeronautics.

REFERENCES

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2. Eckert, B.: Axialgebläse mit hoher Druckziffer. Jahrb. 1940, d. D. Luftfahrtforschung, R. Oldenbourg (München).
3. Eckert, B., and Mlaker S.: Herstellung der Schaufeln für Axialgebläse. Dtsch. Luftf.-Forsch. FB 1291.

TABLE 1. - COMPARISON OF THE VARIOUS TYPES OF CONSTRUCTION

	Figure	Number of stages	Stage pressure factor ψ	Total pressure factor $\Sigma\psi$	l/D	Pressure head H (m)	Comparison factor x
Supercharger	1	3	0.8	2.4	1.056	9,570	^a 0.44
Supercharger	2	3	0.8	2.4	1.06	9,570	^a 0.442
Counterrotating supercharger with one gearing and intermediate guide vanes	3	4	0.7	2.8	0.833	11,170	^a 0.298
Counterrotating supercharger with two gearings	4	4	0.7	2.8	0.7225	11,170	^a 0.258
Counterrotating supercharger with two gearings and exit guide vanes	5	5	0.7	3.6	0.917	14,000	^a 0.255
Counterrotating supercharger with exit guide vanes	6	5	0.7	3.6	0.804	^b 14,000	^c 0.223

^aPeripheral speed u_a limited by considerations of flow theory so that $u_a < a$ (a = speed of sound).

^bCalculated as if $u_a = 280$ meters per second.

^cPeripheral speed u_a limited by strength of materials so that $u_a < 150$ meters per second.



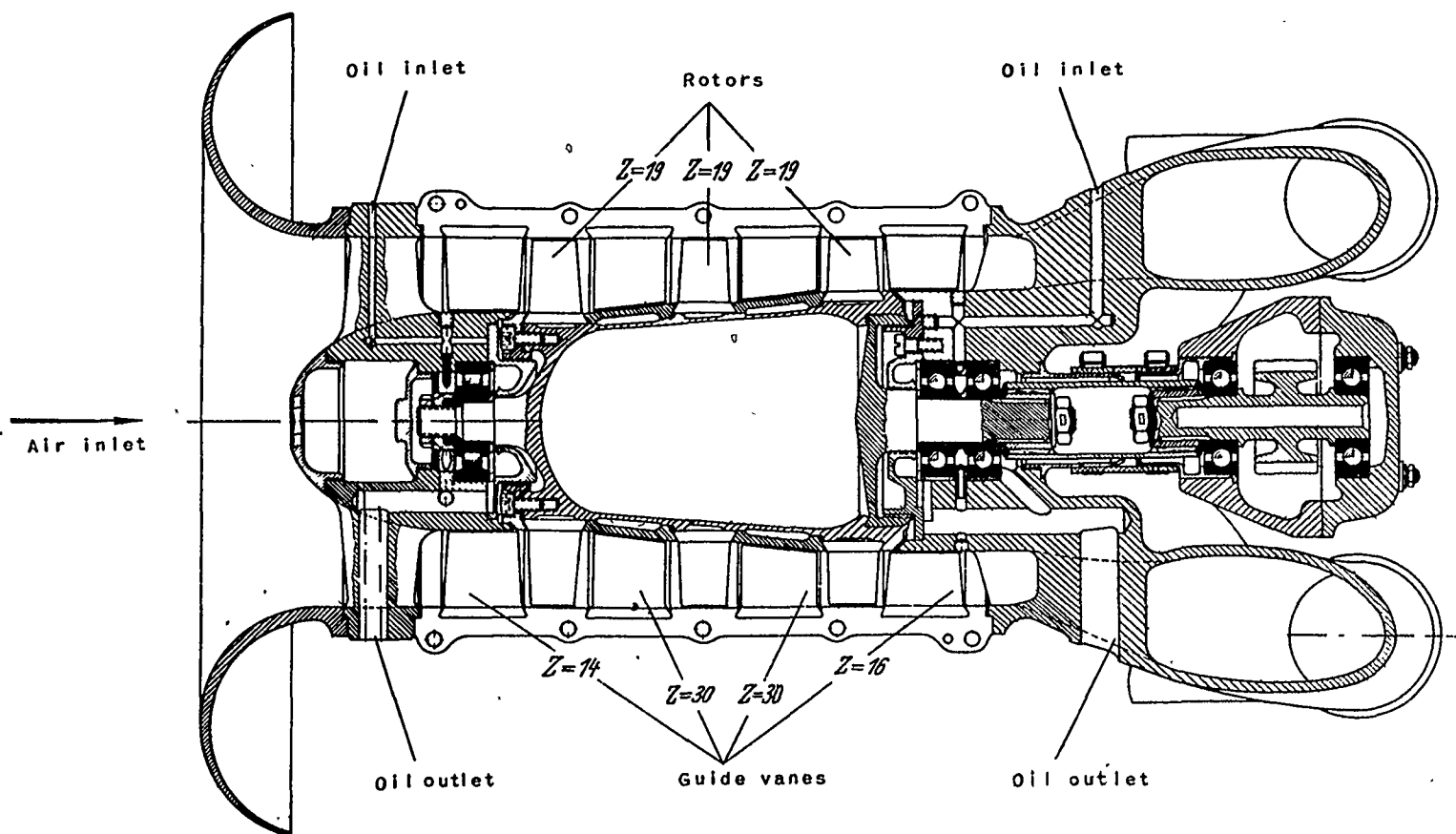


Figure 2. - Three-stage axial blower with guide vanes. $G = 0.85$ kilogram per second;
 $H_{ad} = 6600$ meters.

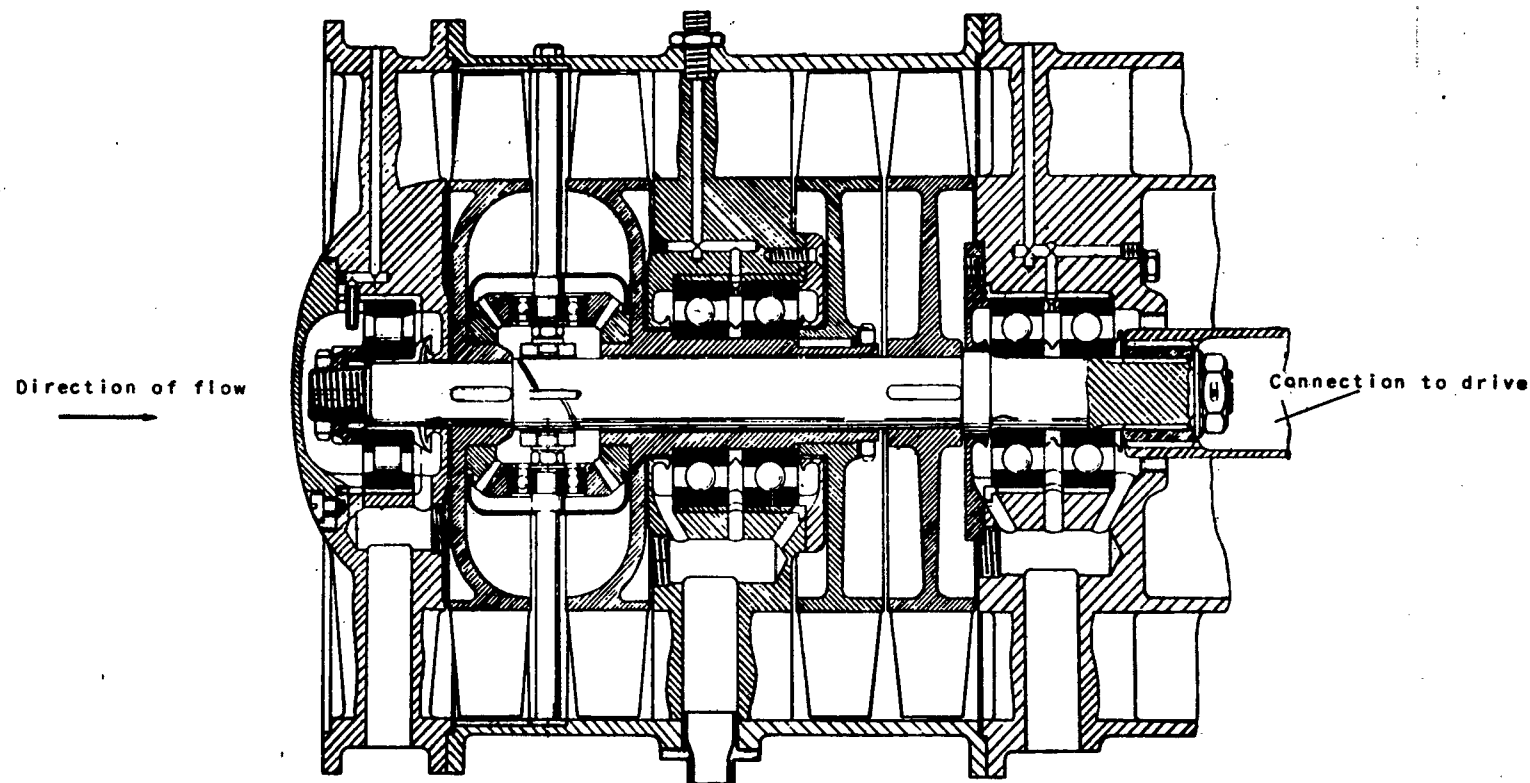
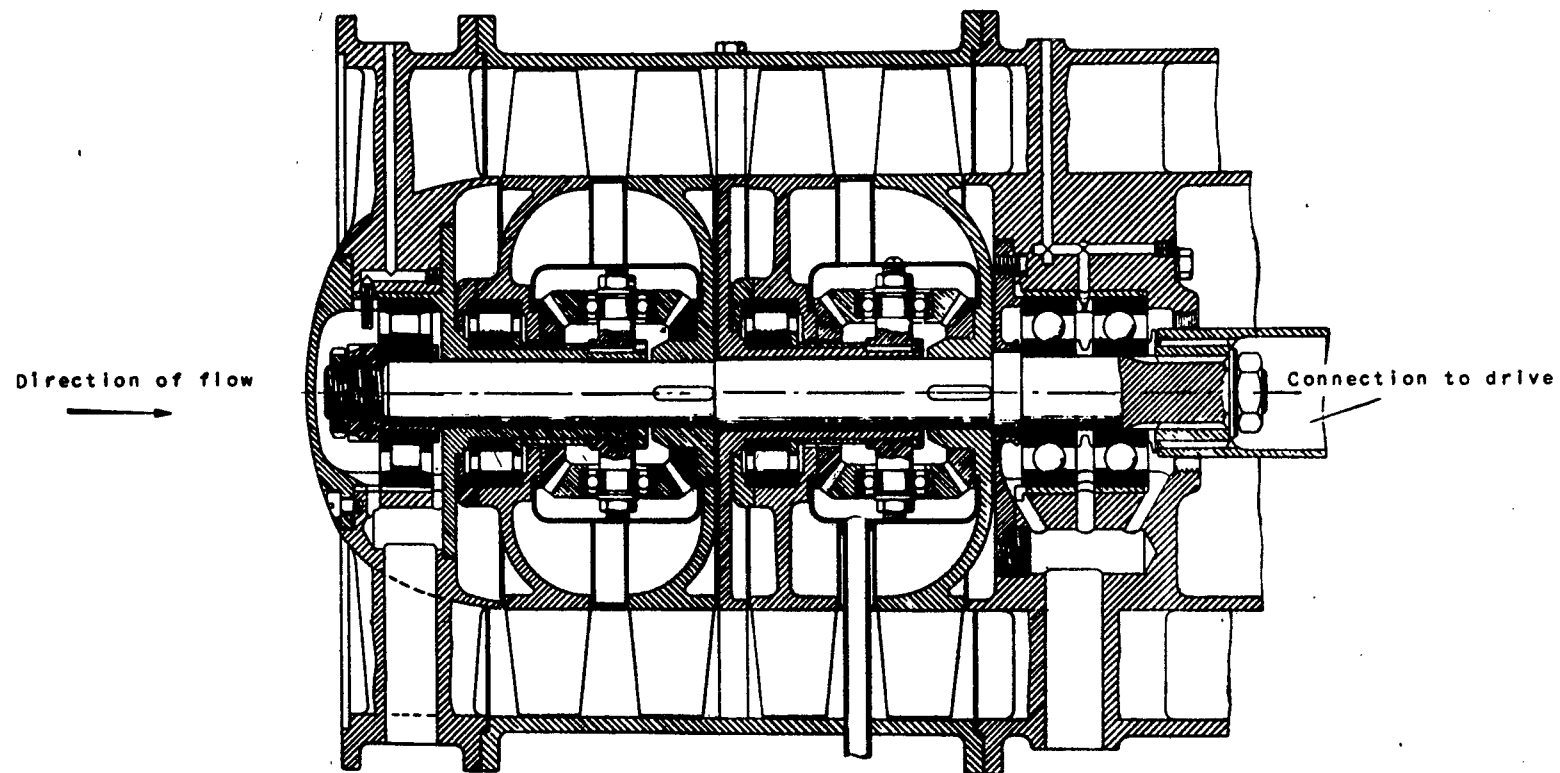


Figure 3. - Four-stage axial supercharger with counterrotating rotors, a gearing, and intermediate guide vanes.

Fig. 4



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Figure 4. - Four-stage axial supercharger with counterrotating rotors and two gearings.

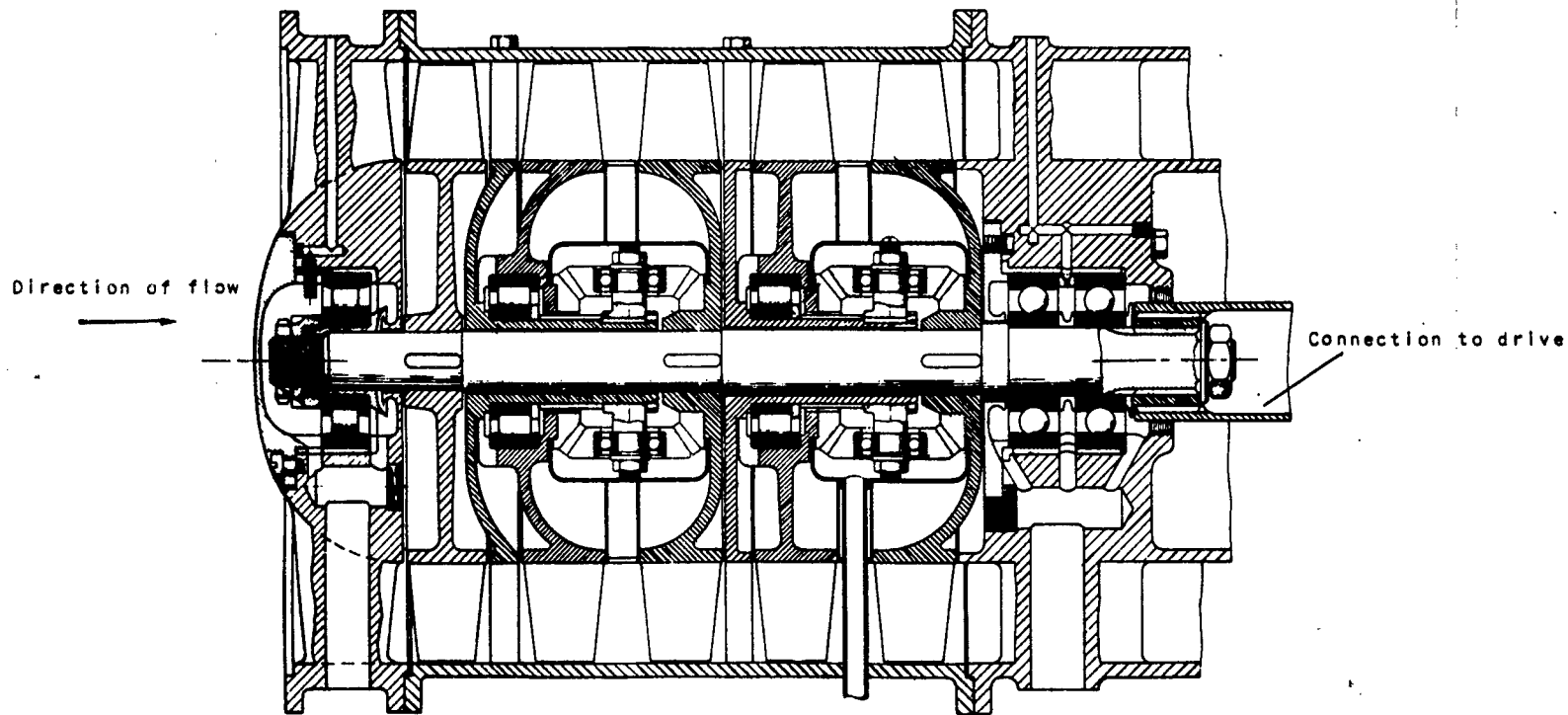


Figure 5. - Five-stage axial supercharger with counterrotating rotors and two gearings.

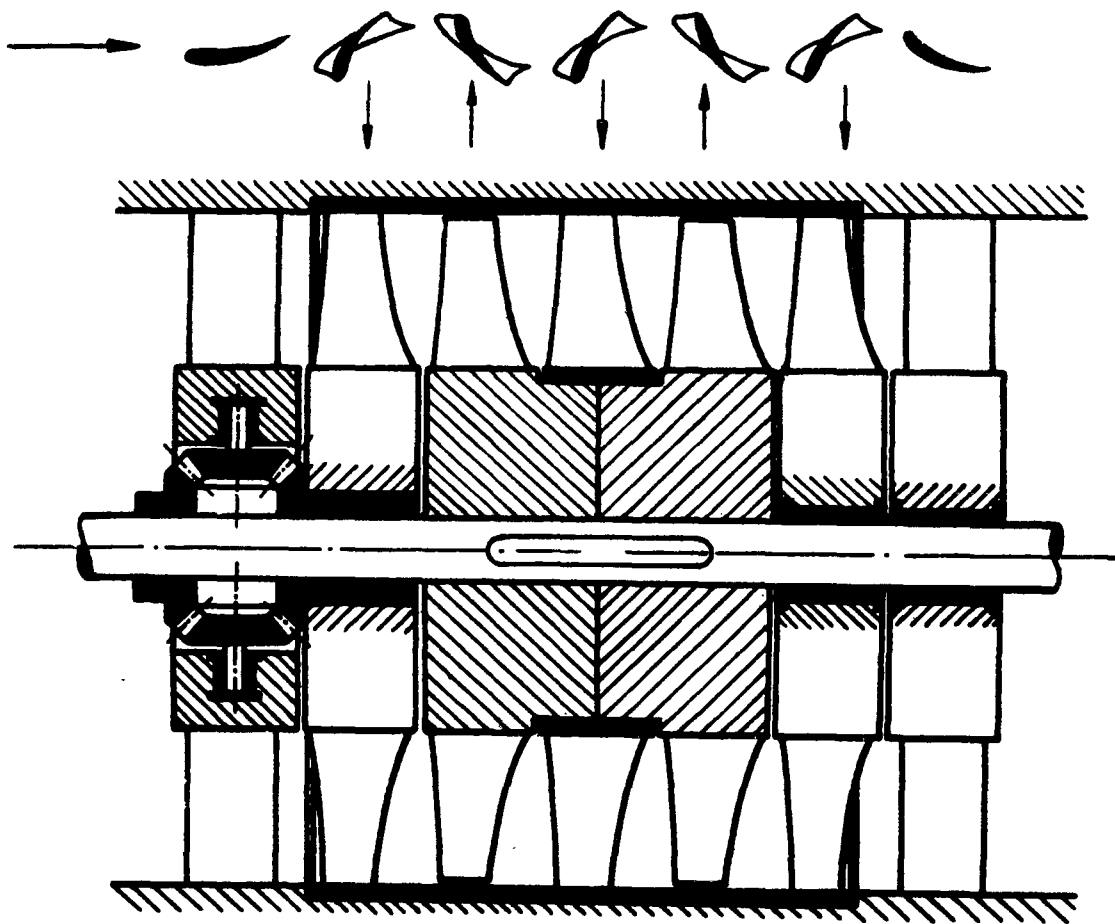


Figure 6. - Five-stage counterrotating axial blower with outside rotating drum. (From reference 1.)



Author

Blowers, Axial

Superchargers, Axial

X Superchargers, Counter-rotating

X Slow - Superchargers